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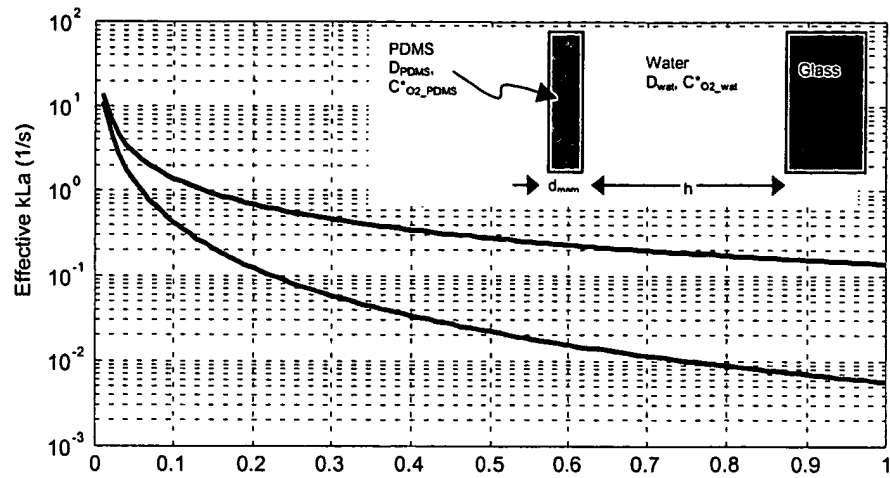
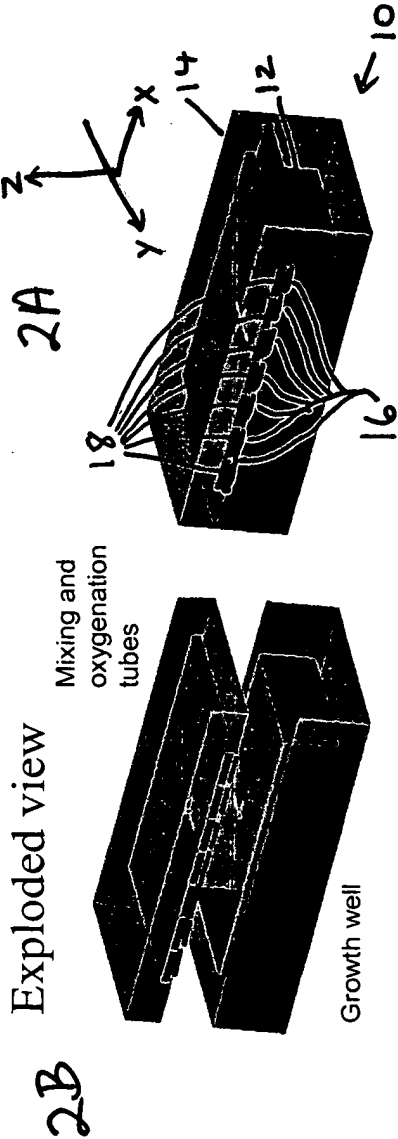


Figure 1

FIGURE 2



Actuation pattern (cross section view)

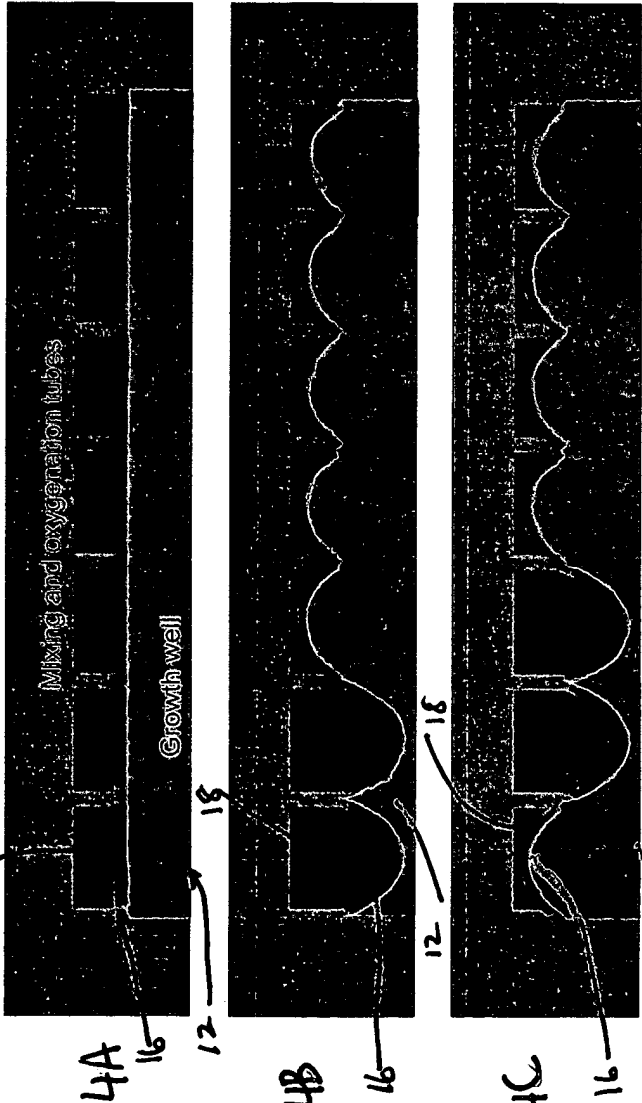
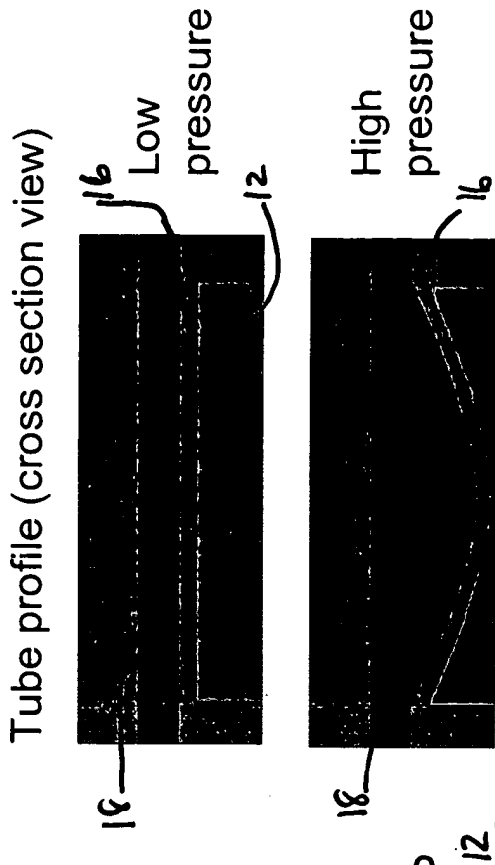


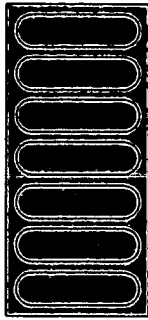
FIGURE 4

This pattern proceeds to the right and wraps around to the left when it reaches the right edge. The next slide shows the entire pattern.

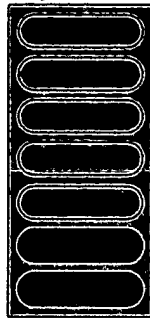
FIGURE 3



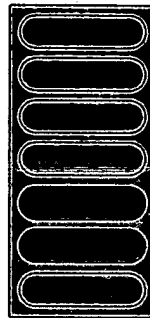
Top views (dark blue indicates pressurization), arrows indicate fluid flow



All tubes un-pressurized



Two left tubes pressurized, fluid is displaced to the right and up into the un-pressurized tubes.



Second tube stays pressurized, first tube is displaced and third tube is pressurized. Fluid is pushed to the right by third tube and around second tube to push up first tube.

FIGURE 5

Approximate flow for straight tubes

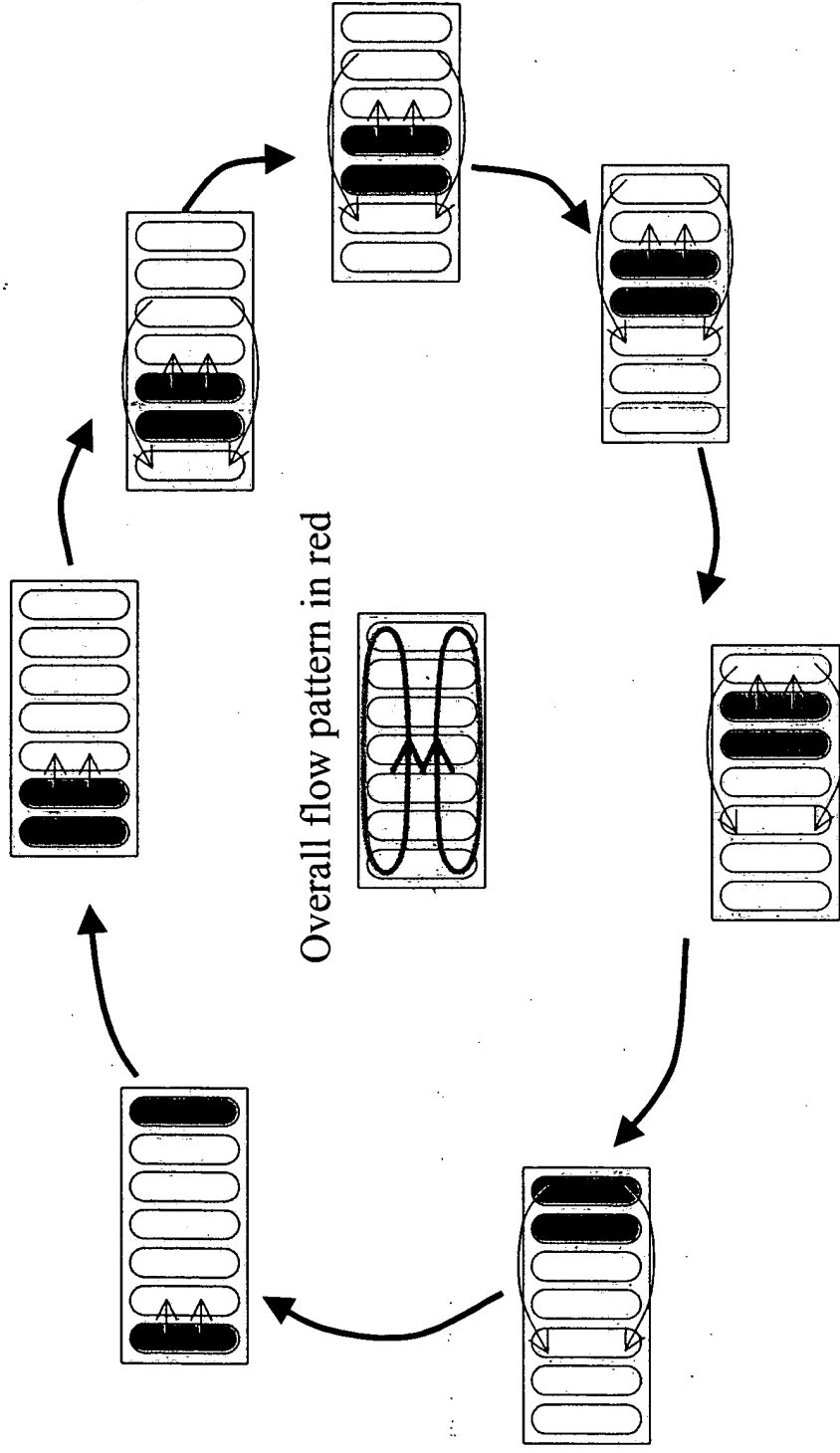
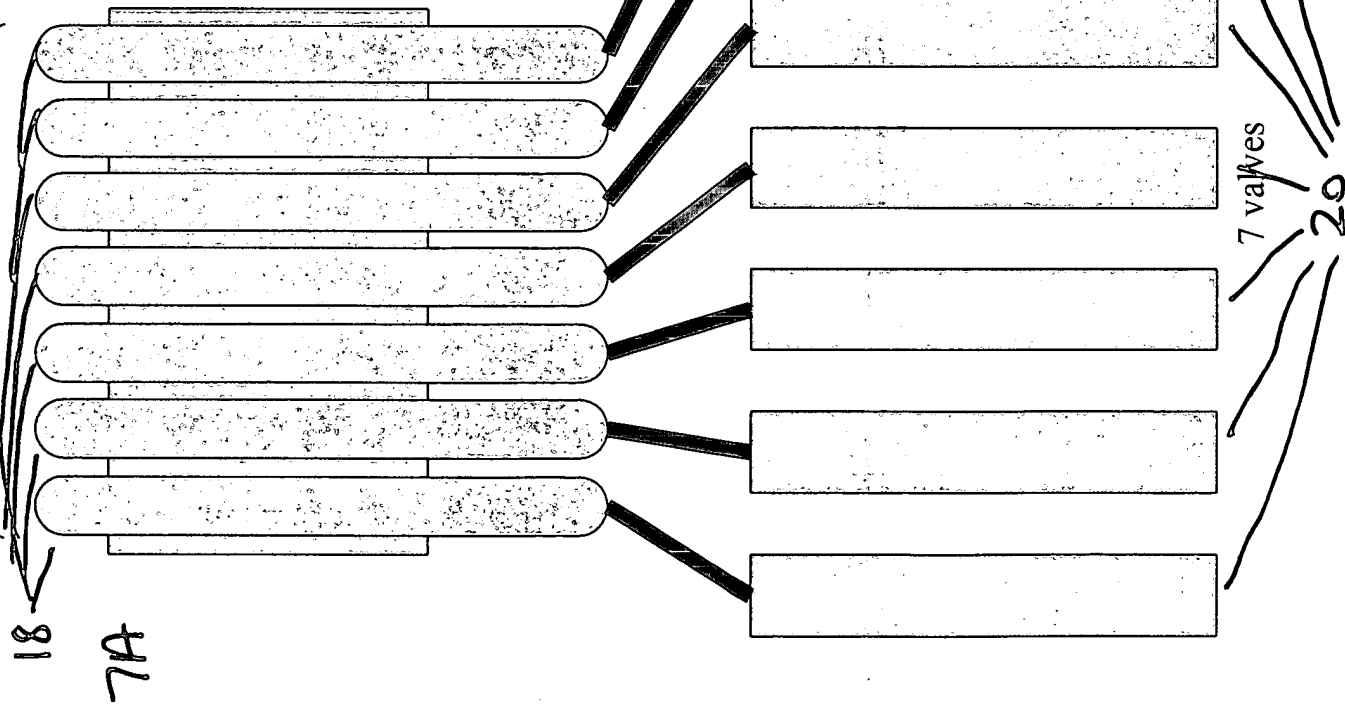


FIGURE 6

FIGURE 7

7 tubes and 7 valves, each tube individually controllable

Left tube in each group is first to pressurize/depressurize, right tube last to pressurize/depressurize. Small connection between left/right tubes causes the delay (high flow resistance) Some flexibility is lost, but you can reduce the number of actuators.



7 tubes and 3 valves, each color group is controllable.

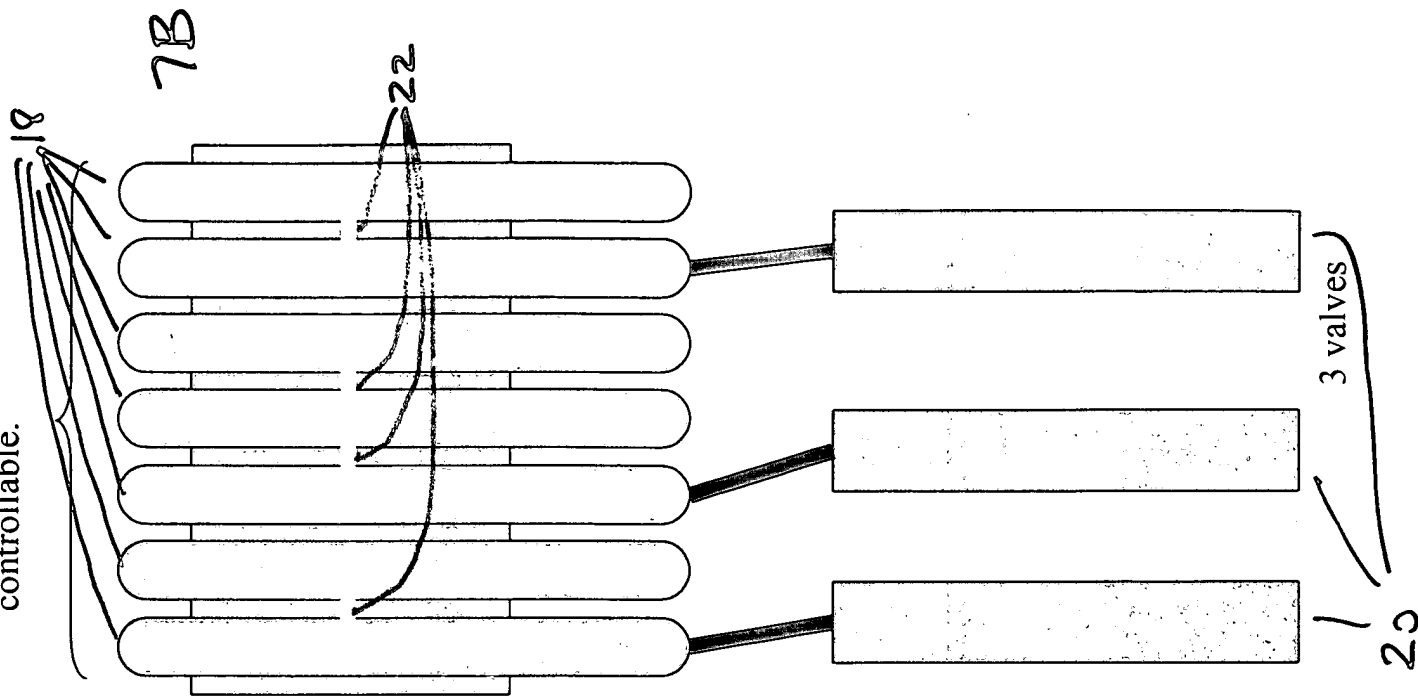
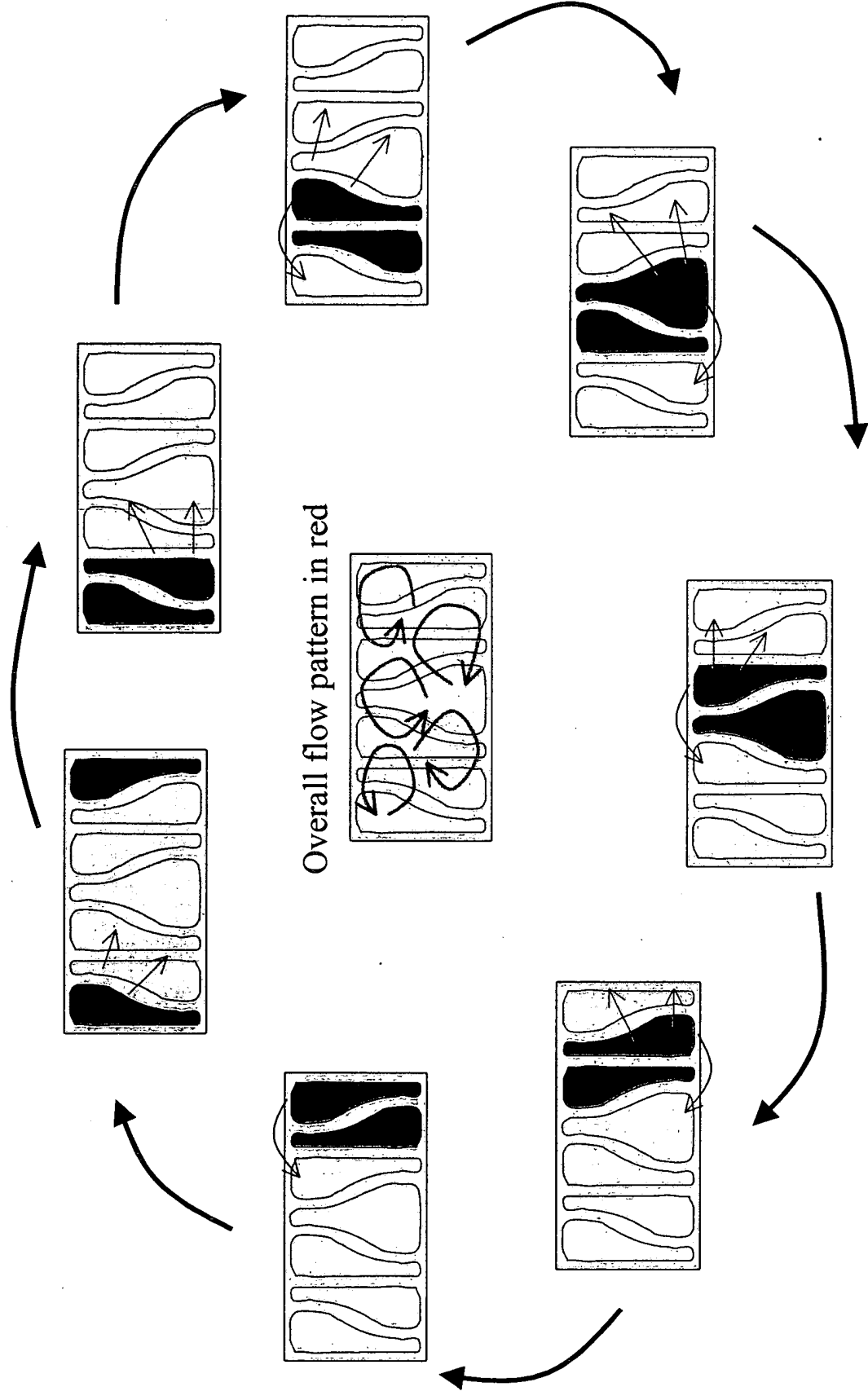
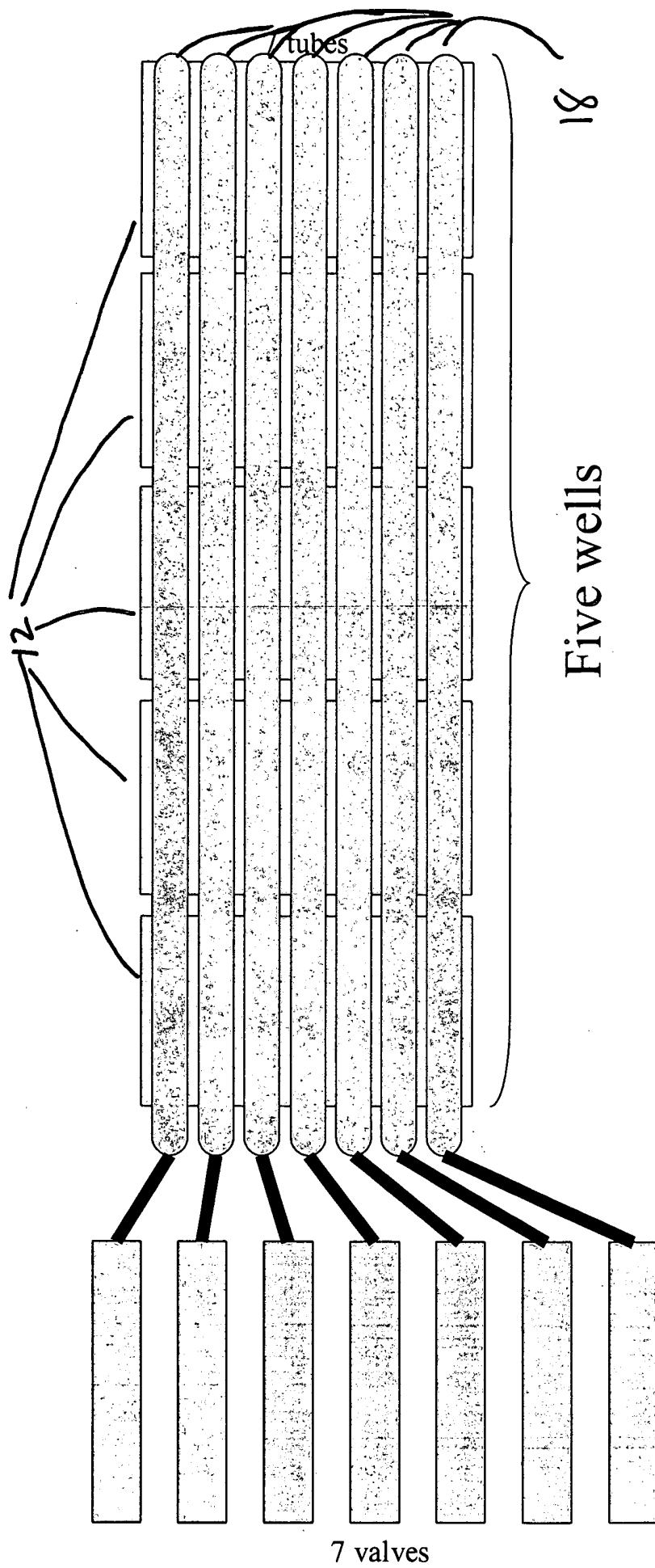


FIGURE 8

Approximate flow for wiggle (variable width tubes)





Five wells

FIGURE 9A

7 individual high pressure

lines (no communication, or

small communication between tubes

compared to flow rate out tube)

Airflow for open valve

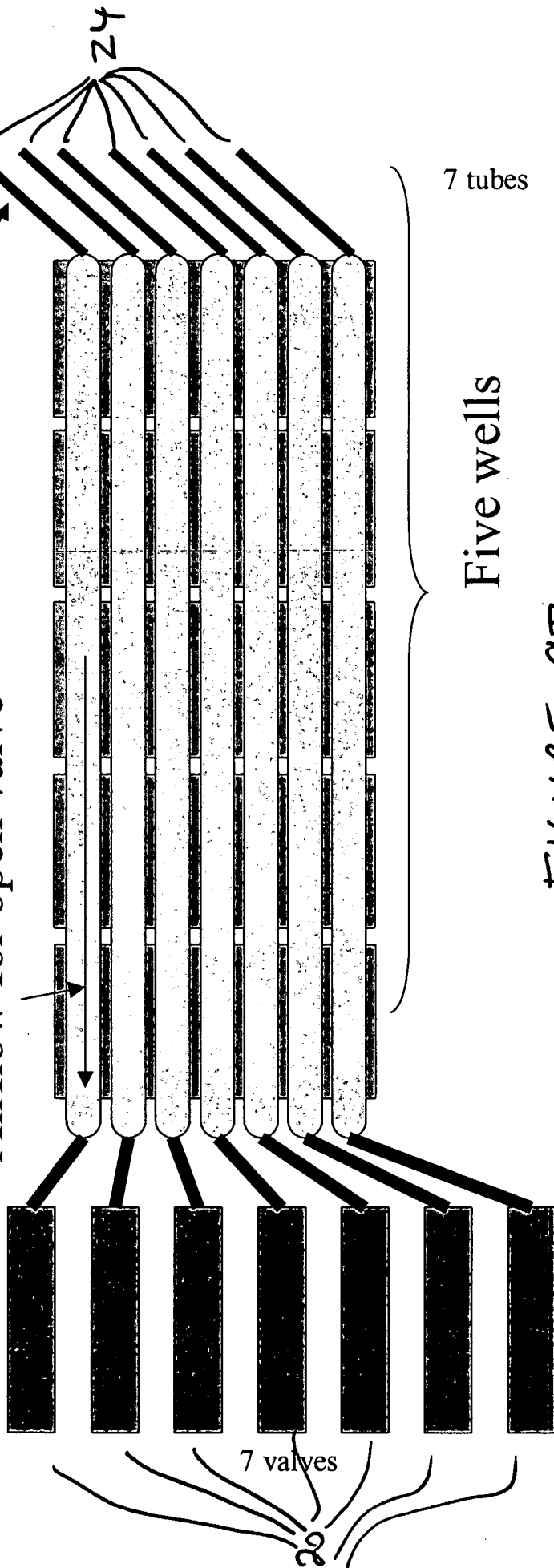


FIGURE 9B

7 individual valves open means air flows and tube is not pressurized. Closed means tube is pressurized to whatever the individual high pressure line pressure is.

Fabrication process

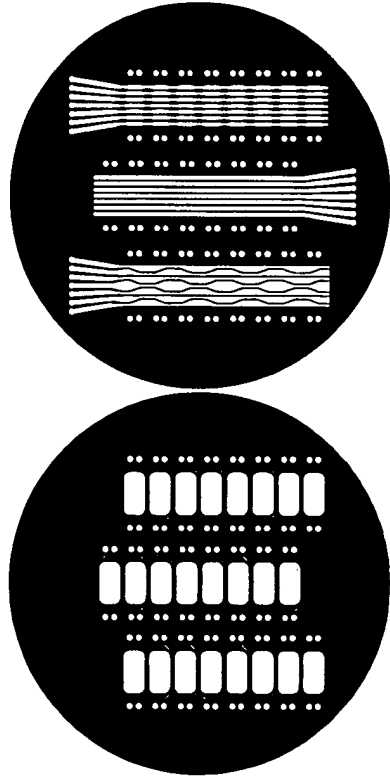
FIGURE 10

Make mold: SU-8
photolithography

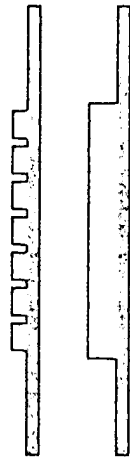
A



Spin on SU-8,
pre-bake



Expose with transparency mask



Post-exposure bake, develop,
silanize

Elastomer casting

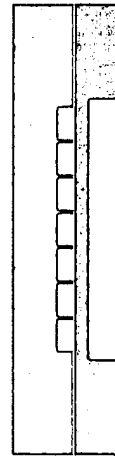
50min 65°C 8:1



B



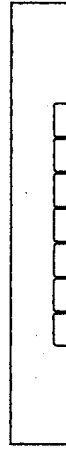
20min 65°C 20:1



E

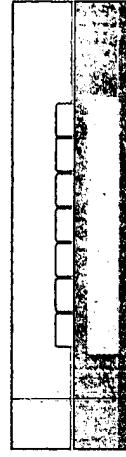
Cut out individual devices
and peel from mold

C



Peel and punch holes
to access tubes

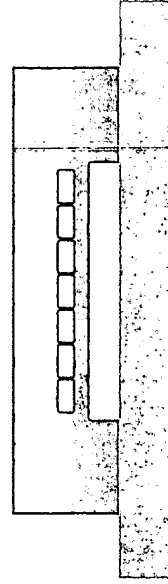
D



Align and seal

Full Cure 2 hrs
65°C

F

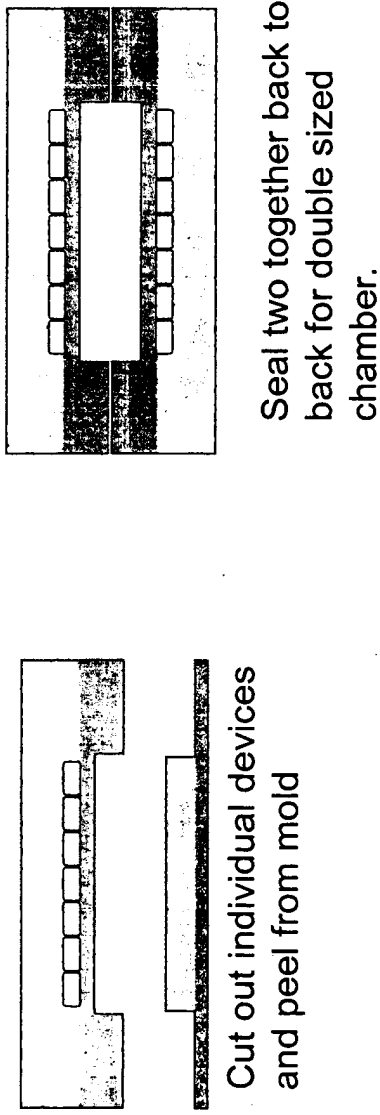


Bake ~2 hrs 65°C

Seal to microscope slide

FIGURE 11

Another variation:



Another embodiment

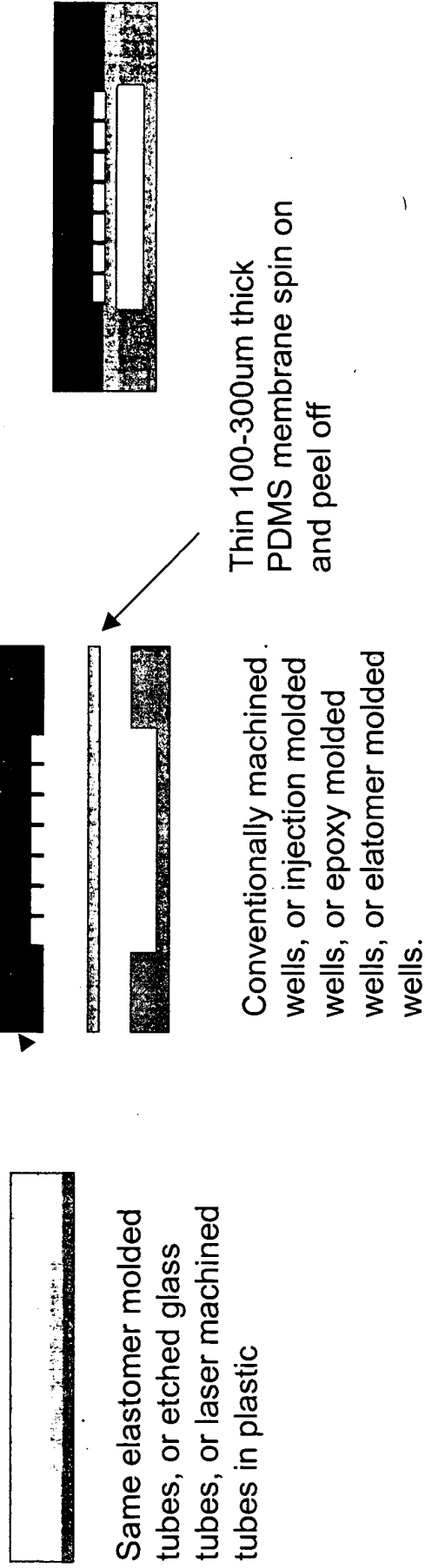
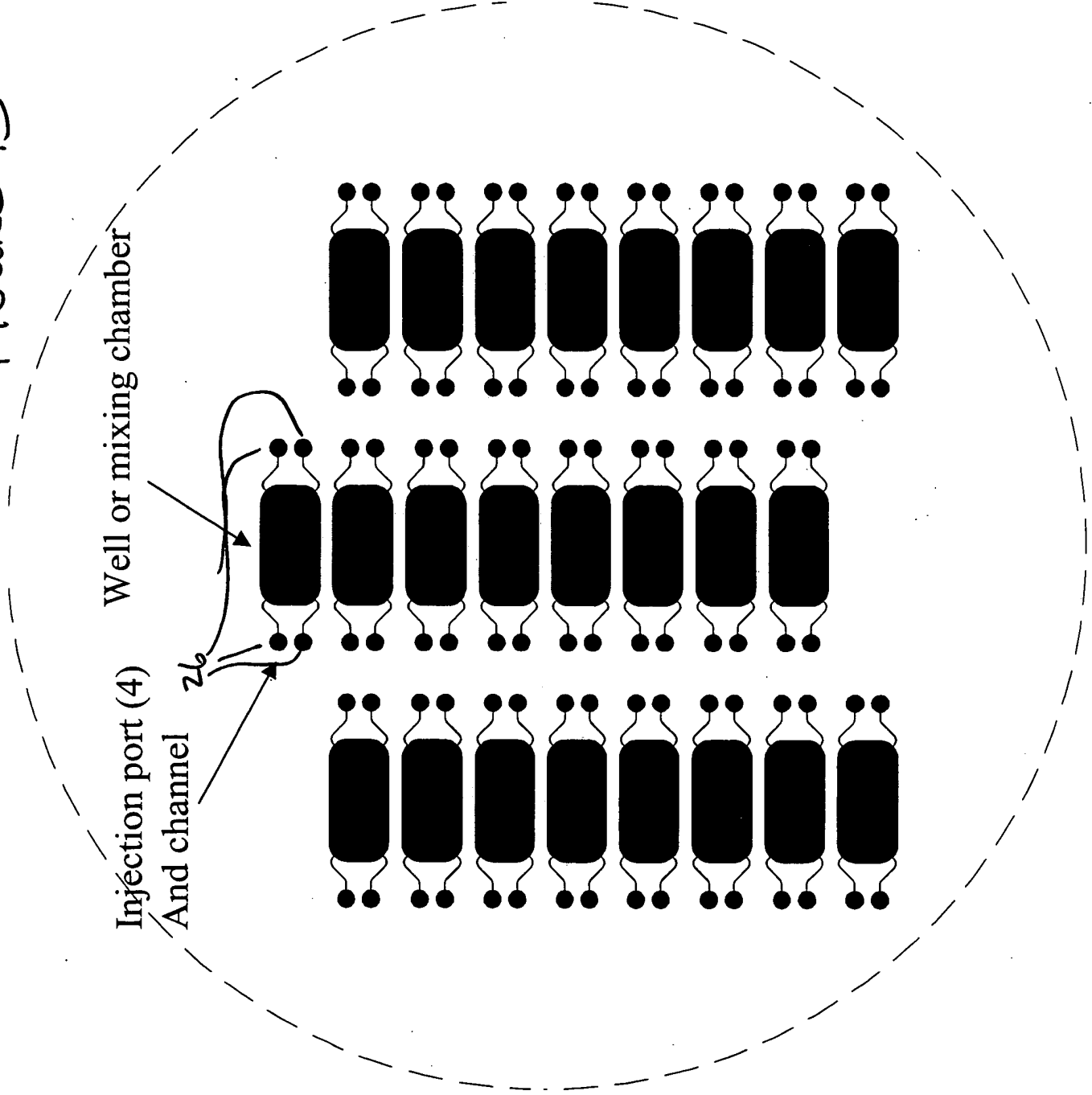


FIGURE 12

FIGURE 13



This is the mask for the well, or chamber mold. The dashed circle is 3.5 inches in diameter and each well is 5mm x 10mm. The spacing between the wells is 1mm.

The dark areas on the mask will result in raised structures (typ: 300-500 μ m) on a silicon wafer substrate to form the mold. After casting the elastomer and peeling it off, the dark areas will be cavities in the silicone elastomer.

FIGURE 14

This is the mask for three different kinds of tubes. The left is the "wobble tube" to drive flow transverse to the peristalsis direction. The middle is the standard straight tube, and the right are straight tubes with narrower regions near the edges of the wells. (The next slide shows the two masks overlaid)

The dark areas on the mask will result in raised structures (typ: 200-400 μm) on a silicon wafer substrate to form the mold. After casting the elastomer and peeling it off, the dark areas will be cavities in the silicone elastomer.

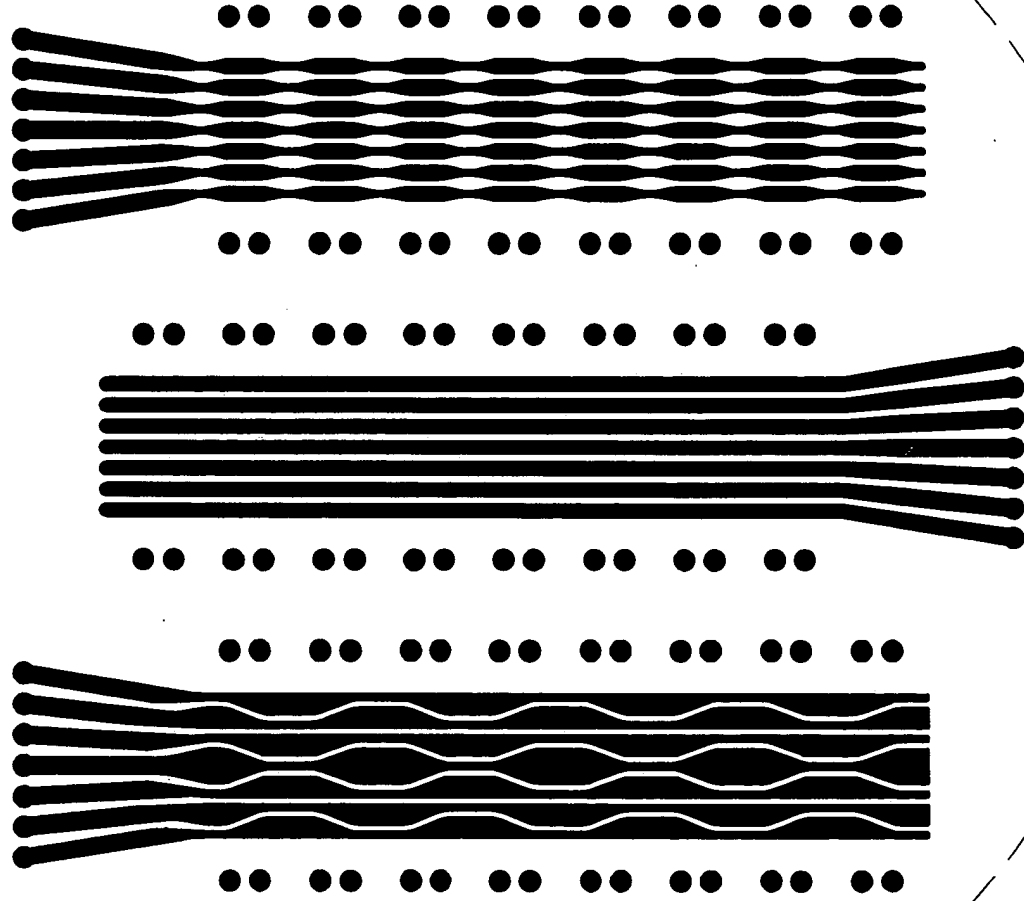
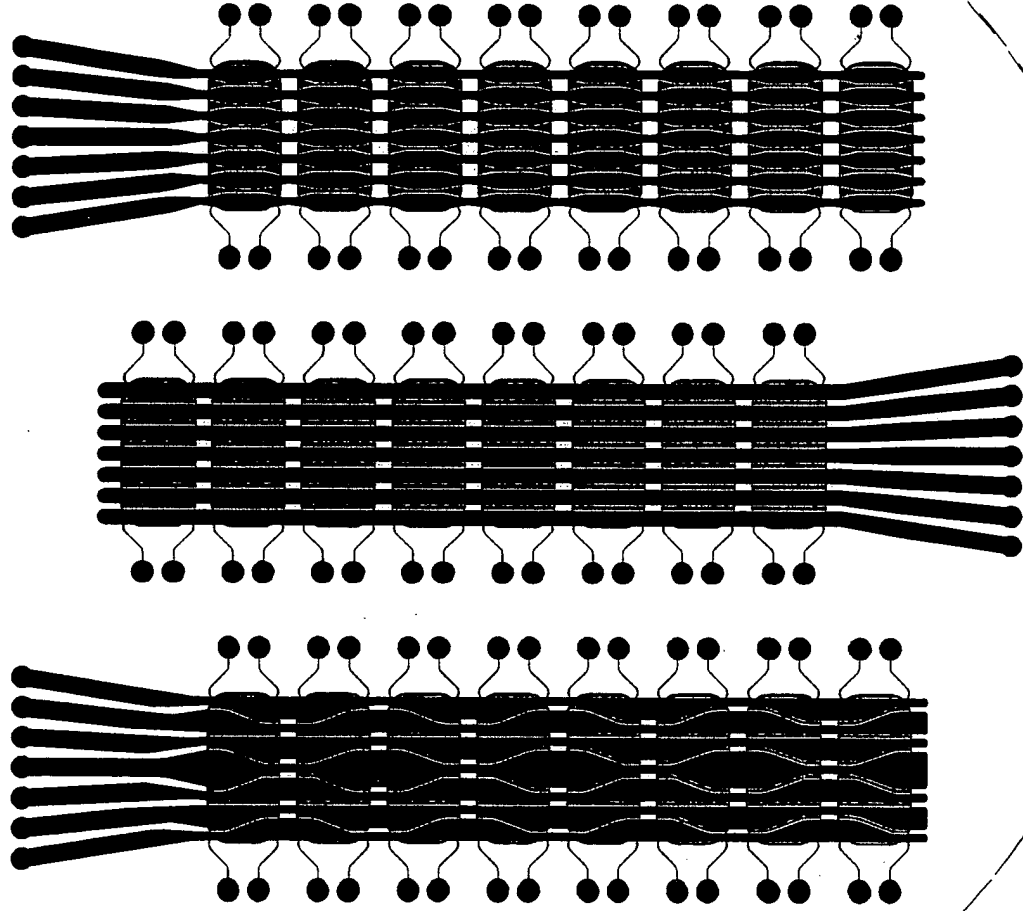


FIGURE 15

This shows the two masks overlaid.

A key part of the design is the scalability. Note that only seven macroscopic actuators (Lee company solenoid valves – see later slide). Are required to actuate 8 wells because each tube crosses over eight wells. By making it longer, scalability would improve. (7 valves actuate 16, or 32 wells) Current implementations are limited by the clean room processing tubes, and easy availability of 1x3 inch microscope slides substrates. Minimizing the number of actuators is important to reduce overall system size and to keep to simplify the assembly of the macroscopic actuators.



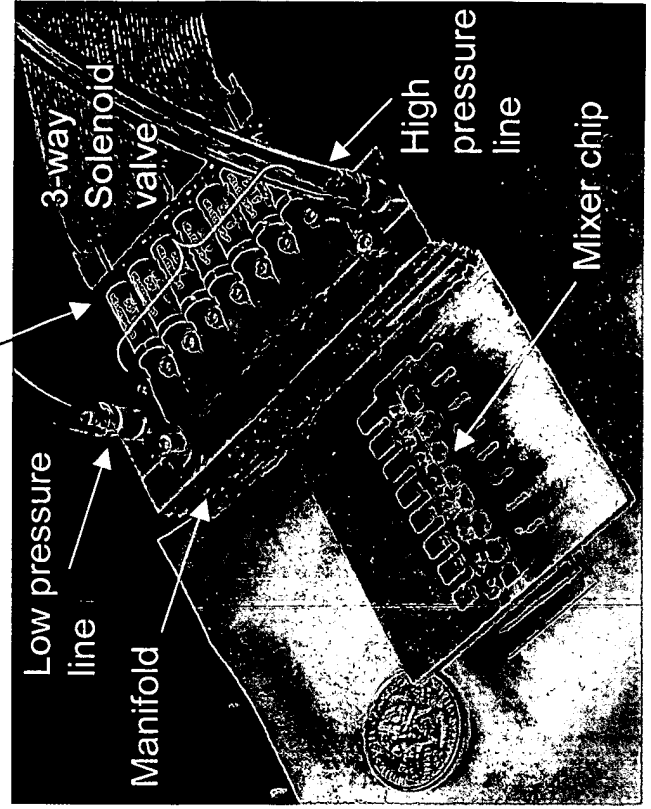
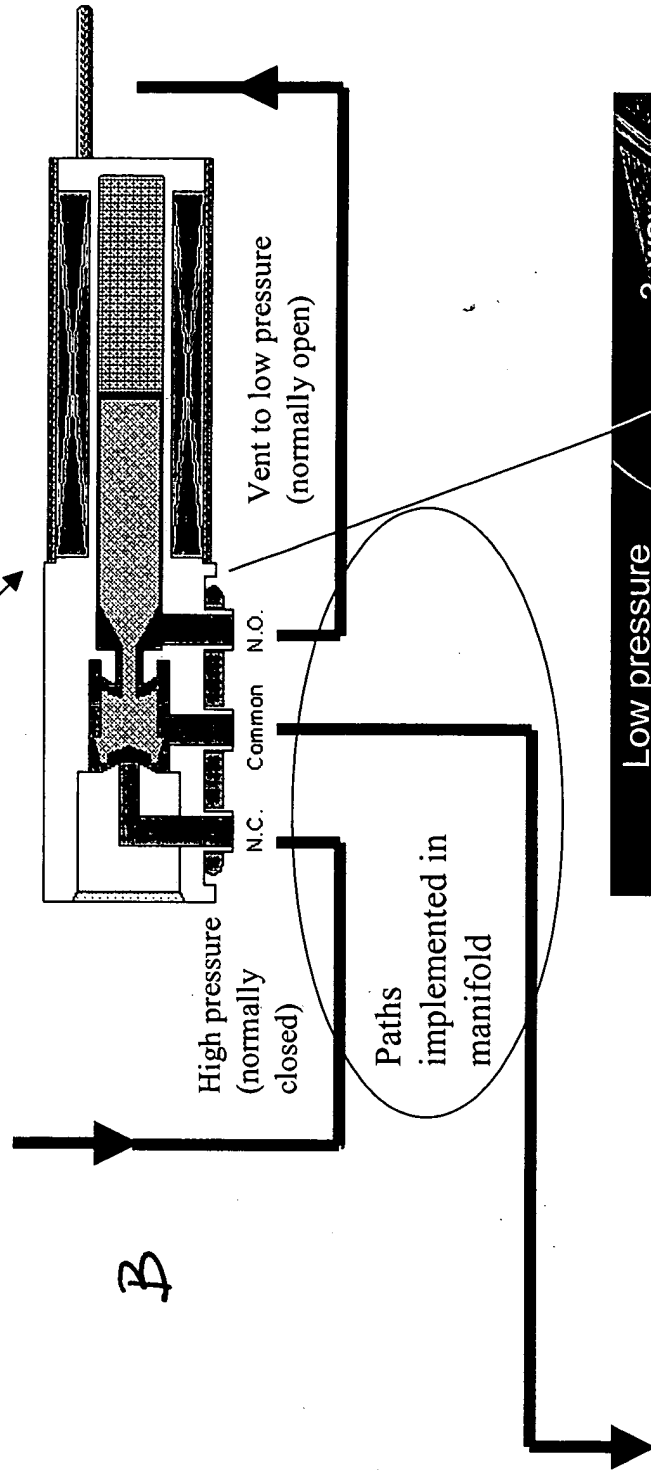


FIGURE 16

Exploded view of manifold, which mainly serves to reduce the pitch of the solenoid valves down to the pitch of the acutation ports.

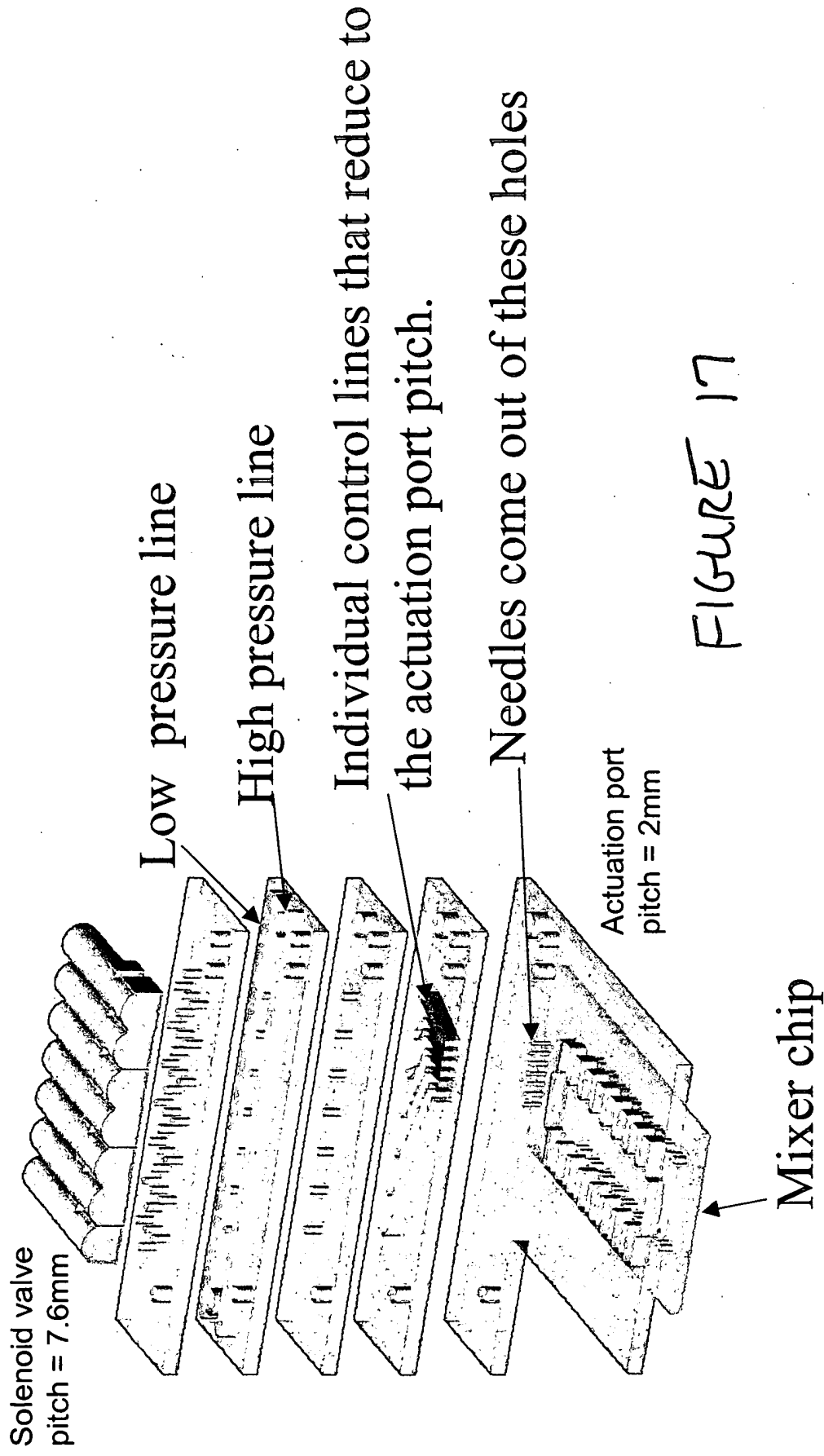


FIGURE 17

FIGURE 18

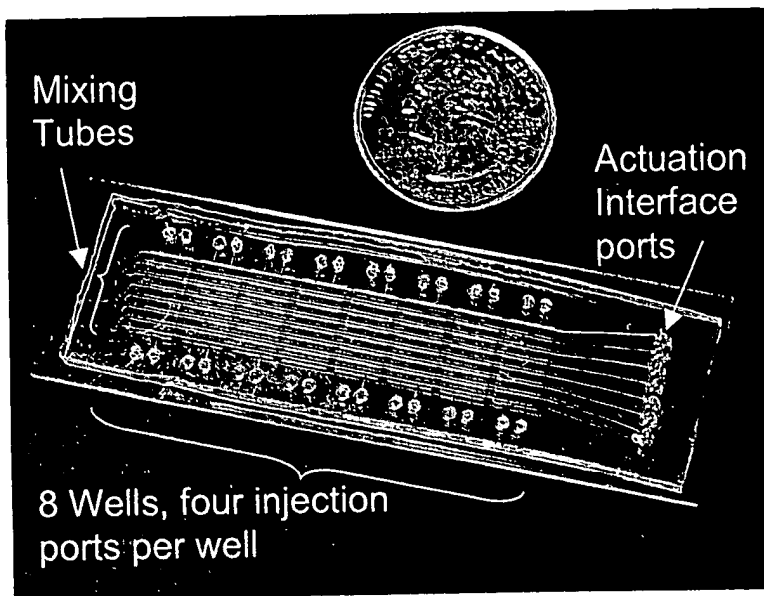


FIGURE 19

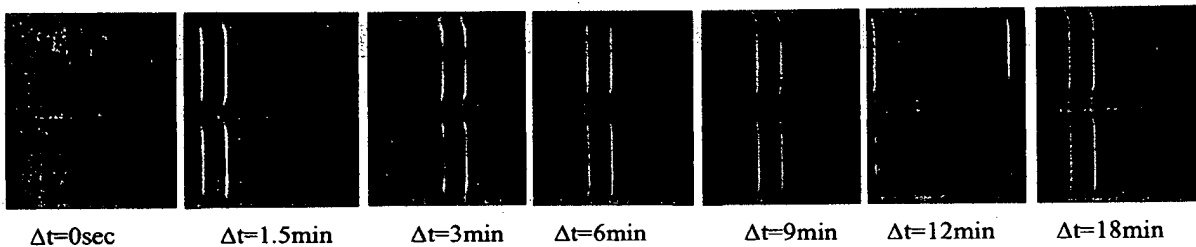
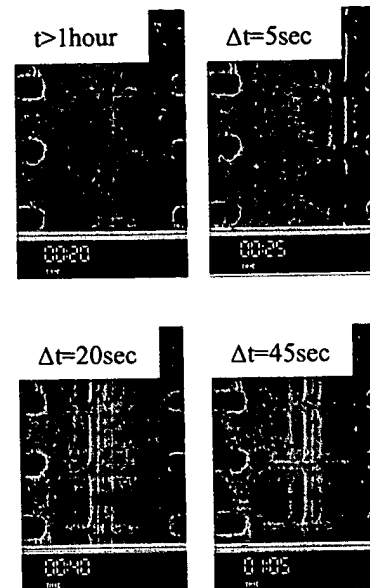


FIGURE 20

FIGURE 21



$t \sim 5\text{min}$



$\Delta t = 1\text{sec}$



$\Delta t = 2\text{sec}$



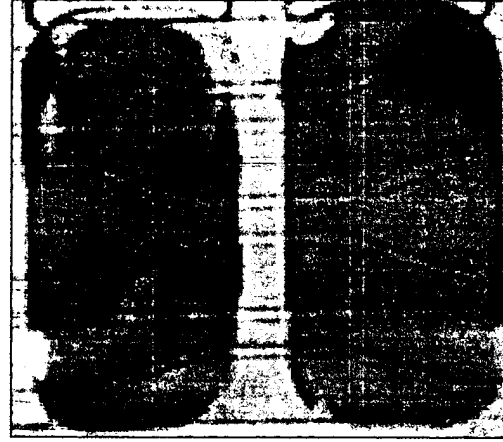
$\Delta t = 3\text{sec}$



$\Delta t = 4\text{sec}$



$\Delta t = 5\text{sec}$



$\Delta t = 6\text{sec}$



$\Delta t = 10\text{sec}$

Note, the light areas look light because the tubes are deflected and the dye is pushed away, allowing more white background to show through. 8psi, 100Hz.

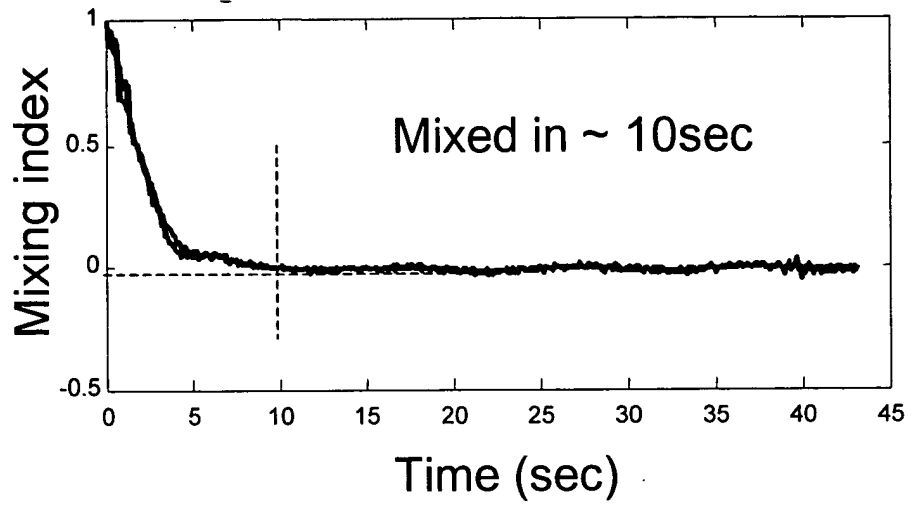
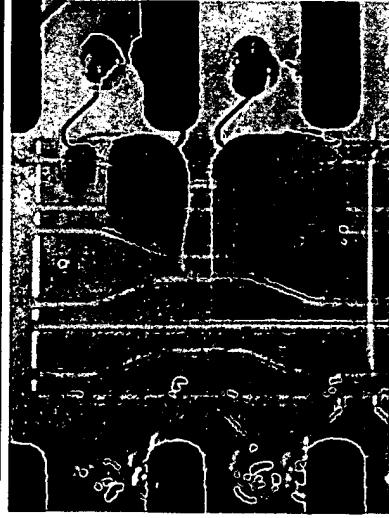


FIGURE 22

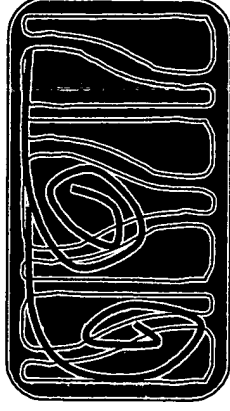
FIGURE 23

Mixing Results



Slow, 10Hz actuation rate, 8psi

Corn syrup



Water

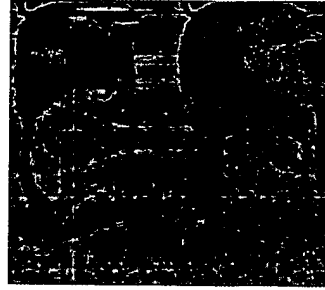
Upper/lower half symmetry broken, no more separated flow, but sometimes vortices don't mix.



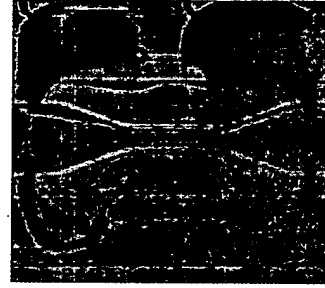
Corn syrup

Water

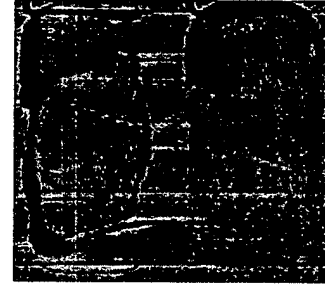
Fast, 100Hz actuation rate, 8psi



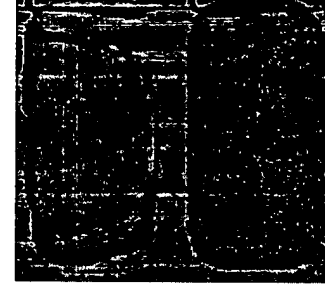
$\Delta t=1\text{sec}$



$\Delta t=2\text{sec}$



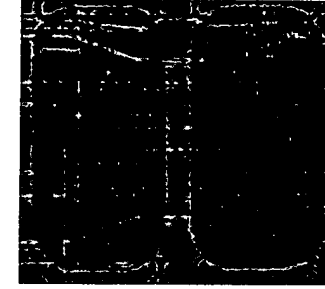
$\Delta t=4\text{sec}$



$\Delta t=8\text{sec}$

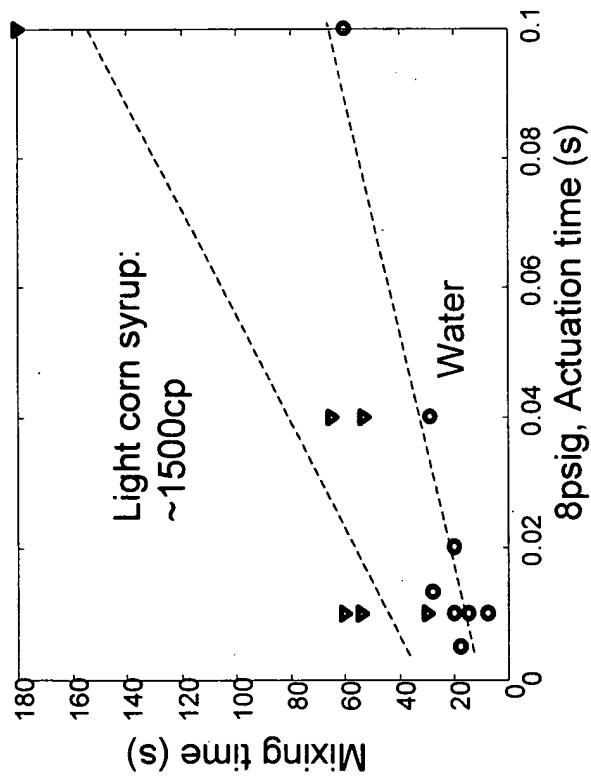


$\Delta t=16\text{sec}$

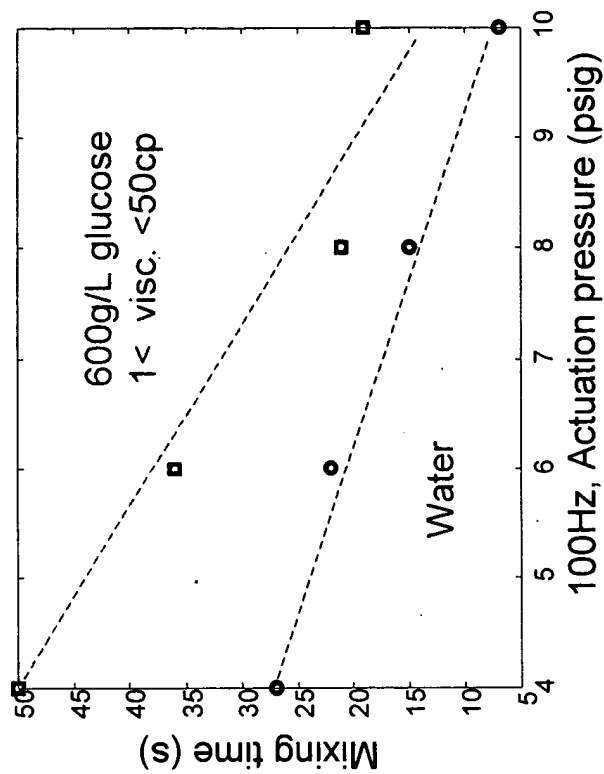


$\Delta t=32\text{sec}$

Mixing trends



A



B

FIGURE 24